Improving Algebra Learning and Collaboration through Collaborative Extensions to the Algebra Cognitive Tutor

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Preliminary Note

We propose to present a poster based on a research project we are conducting within the Pittsburgh Science of Learning Center, one of three NSF-funded learning science centers in the United States. The project commenced in January 2005. On the poster we present the project idea, describe the collaboration scripts we have developed, and give a short description of the empirical work that is in progress. While we have some preliminary results on our script approaches, the main empirical studies are not yet completed. However, we think that the project idea is very innovative and of substantial interest to the CSCL community, particularly since the theme of this years' CSCL conference is "The next ten years!"

Project Description

A number of studies have shown that instruction with Cognitive Tutors, developed by Anderson, Corbett, Koedinger, & Pelletier (1995) can improve student learning in the domain of algebra. For instance, use of the Algebra Cognitive Tutor has been shown to improve learning by about one standard deviation over traditional classroom instruction on measures of algebra understanding (Koedinger, Anderson, Hadley, & Mark, 1997; Koedinger, Corbett, Ritter, & Shapiro, 2000). A Cognitive Tutor is a particular type of intelligent tutor (Wenger, 1987) that supports "guided learning by doing" – a pedagogical approach in which students try to solve problems while a tutor "watches" and intervenes as requested by the user or as deemed necessary by the Tutor. In particular, a Cognitive Tutor compares a student's actions during problem solving to a model of correct problem solving steps and provides context-sensitive hints, error feedback, and individualized problem selection.

Up until now, Cognitive Tutors have been used exclusively in one-on-one instructional scenarios; that is, a computer tutor assisting a single student. However, Carnegie Learning, the company spawned from the research and development of Cognitive Tutors, explicitly provides Algebra Cognitive Tutors for what is termed the "Collaborative Classroom" (Carnegie Learning, 2003). In such a classroom, the setting in which the Algebra I Cognitive Tutor[1] is situated is distinctly cooperative and multi-party. In these Collaborative Classrooms, the teachers act more as facilitators than as lecturers, and students are encouraged to work together in groups to solve algebra problems.

Indeed, much research on learning has demonstrated the potential effectiveness of collaboration for improving students' problem-solving and learning (e.g., Slavin, 1992; Johnson & Johnson, 1990). Some particular merits of collaborative problem-solving include: encouraging students to verbalize their thinking; increasing students' responsibility for their own learning; encouraging students to work together; adding variety to regular classroom routines; increasing the possibility of students solving or examining problems in a variety of ways; and enabling teachers to individualize instruction and to accommodate students' needs, interests, and abilities (Webb, 1991; Webb, Trooper & Fall, 1995).

Given the collaborative setting within which Cognitive Tutors are used, as well as research that

[1] Carnegie Learning provides both an Algebra I and an Algebra II Cognitive Tutor. For the purpose of this proposal, "Algebra Cognitive Tutor" refers to the tutor for Algebra I.

provides evidence for the potential benefits of collaboration, we are interested in the following questions: Could collaborative features implemented directly within the Cognitive Tutors – features that facilitate students working together rather than individually on algebra problems – improve algebra learning? Further, could those features improve students' collaborative skills as they tackle future problems?

Our approach to answering these questions relies on research that shows that collaboration will only benefit students' mathematics learning if implemented and supported adequately (Watson & Chick, 2001, Good, Mulryan, & McCaslin, 1992). These findings have clear implications for the approach that we take in promoting collaboration within the context of the Algebra Cognitive Tutor. We provide guidance necessary for fruitful collaboration to occur through *collaboration scripts*, a form of support in which collaboration is structured and directed, either explicitly or implicitly. In a collaboration script, collaborating partners are guided through a sequence of interaction phases. Each phase has designated activities and roles for the participants, similar to a movie script. The script is expected to promote learning by prompting cognitive, meta-cognitive and social processes that might otherwise not occur.

There is ample empirical evidence that collaboration scripts are effective measures for supporting positive collaborative interactions and thereby promoting *domain-content learning* (e.g. Hron, Hesse, Reinhard, & Picard, 1997; King, 1998; O'Donnell, 1999; Weinberger, Reiserer, Ertl, Fischer, & Mandl, in press). The domain learning effect of scripting is mainly attributed to engaging students in elaborative cognitive activities like posing questions, providing explanations or giving feedback on a peer's contributions (Ploetzner, Dillenbourg, Preier, & Traum, 1999; Teasley, 1995). Furthermore, the social constructivist literature (e.g., Forman, Minick, & Stone, 1993; Resnick, Levine, & Teasley, 1991) emphasizes the importance of elaborative cognitive activities in a social context for learning.

In addition to promoting domain-content learning, some of our own earlier work provides evidence that scripted collaboration can improve students' *collaboration skills* such that they perform *and* collaborate better on subsequent tasks without script support (Rummel & Spada, 2005, Rummel & Spada, submitted). In this work dyads of medical and psychology students learned to alternate phases of individual and collaborative work, which given the interdisciplinary nature of the tasks, was identified as an important predictor for the quality of their joint problem solution. Other collaboration script approaches have also assumed that the learners would internalize relevant elements of the script so that the external scaffolding provided by the script could gradually be terminated as students advance in skill and no longer require such support (e.g. King, 1998).

We experiment with two particular collaboration script approaches, both of which are being integrated with the Algebra I Cognitive Tutor to determine if we can improve both algebra content learning and collaboration skills.

The first approach is a *peer tutoring script* (PTS). In mutual peer tutoring, a student first tutors a partner and is then tutored by the same partner. To be most effective, these tutoring sessions need to be structured (King, Staffieri & Adelgais, 1998); teacher peers must prepare and, during the tutoring session, provide elaborated explanations that lead the peer tutee to constructively use the explanations to solve the problem (Fantuzzo, King, & Heller, 1992). In the PTS we propose, there are three phases: (1) a preparation phase, (2) a collaboration phase, and (3) a meta-evaluation phase. In the *preparation phase*, the "teacher peer" (i.e., the student designated to be the teacher for that session) completes a given algebra problem with guidance from the Cognitive Tutor. This prepares the teacher peer for her tutoring role in the subsequent *collaboration phase*, in which the "peer tutee" (i.e., the student being tutored by the teacher peer) solves a problem analogous to the one that the teacher peer solved during the preparation phase. Although the peer tutee uses a version of the graphical user interface of the Cognitive Tutor when solving the problem, she is provided with help and feedback only from the teacher peer. In the *meta-evaluation phase*, the Cognitive Tutor is again involved, highlighting errors in the peer tutee's solution, and the teacher peer and the peer tutee discuss and correct those problems. During this phase, the Cognitive Tutor also supports a skill-reflection process between the peer tutee and the teacher peer regarding the tutee's learning of the skills. The teacher peer and peer tutee then swap roles and the process is repeated for a new task.

The second approach is what we call a *collaborative problem-solving script* (CPS). The main characteristic of this approach is an interwoven combination of solo and collaborative work. Central to this method is the idea that each student contributes "expertise" acquired from having individually solved a sub-problem prior to the collaboration. These individual pre-solutions then have to be combined to solve a complex collaborative problem. This collaborative problem creates the need for "true" collaboration, which is in contrast to giving students tasks that could be tackled by individuals (Webb, Troper, & Fall, 1995). The CPS approach is based on previous work by Rummel and Spada (2005) in the domain of medical/psychiatric diagnosis, in which an alternation of solo and collaborative work was shown to improve collaboration and problem solving as complementary forms of individual expertise were required to solve a complex problem collaboratively. In the current project we test the effectiveness of a similar approach in the domain of algebra. In the proposed CPS approach, student dyads perform alternating phases of (1) individual problem solving with the Cognitive Tutor, (2) collaborative problem solving with an extended, collaborative version of the Cognitive Tutor, and (3) individual recapitulation. The CPS begins with two students using the Cognitive Tutor to individually solve different sub-problems of an algebra problem (i.e., the *individual phase*). Following this there is a *collaborative phase* in which the pair is presented with a series of questions that require both a combination of their pre-solutions and a collaborative problem-solving effort. The Cognitive Tutor monitors their joint solutions and provides feedback in a manner similar to one-on-one Cognitive Tutoring. After the students have successfully solved the questions raised in the collaborative phase, the students separate again and are individually tested by a series of *recapitulation* questions to assure individual understanding of and accountability for the joint solution (Slavin, 1992) and for reflection on the collaboration process.

Hypotheses and Research Plan

We explore the broad hypothesis that

Instructionally guided collaboration with the peer tutoring script or the collaborative problem-solving script, in conjunction with individual learning with the Algebra I Cognitive Tutor, promotes learning, of both domain-specific algebra skills and collaboration skills.

Sub-hypotheses related to the *domain learning hypothesis* (1) and sub-hypotheses related to the *collaboration learning hypothesis* (2) are investigated:

(1) Scripted collaborative learning within the context of the Algebra I Cognitive Tutor, leads to better learning of domain-specific algebra skills than unscripted collaborative learning or individual learning supported by the Cognitive Tutor.

(2) Scripted collaborative learning within the context of the Algebra I Cognitive Tutor improves students' collaborative skills, thus leading to better subsequent collaborations and better knowledge about collaboration in this context.

The sub-hypotheses are evaluated by looking at different dependent measures as is explained below.

We empirically test our hypotheses in two studies: *Study 1* focuses on the peer tutoring script, while *Study 2* evaluates the collaborative problem-solving script.

In *both studies* three conditions are compared (see Table 1): a condition in which the interaction is guided by a script; a collaborative control condition in which students collaborate without support while solving problems with the Cognitive Tutor; and a condition in which individual students solve the same tasks with Cognitive Tutor support (corresponding to current Cognitive Tutor practice).

Table 1: Experimental conditions in Studies 1 and 2

Condition 1	**Condition 2**	**Condition 3**
Scripted collaborative problem solving	**Collaborative problem-solving without script**	**Individual problem solving**

In both studies, the *collaboration conditions without script* allow us to compare the effects of scripted collaborative activities incorporated in the Cognitive Tutor to the way group work is often implemented in the Algebra Cognitive Tutor classrooms (Ritter, Blessing & Hadley, 2002). From this comparison we can assess the effect our script approaches have on the collaborative process and its outcome. The *individual problem-solving conditions* make it possible to assess the benefits of adding scripted collaboration to the Cognitive Tutor instruction as compared to merely supporting individual learning with the Cognitive Tutor. This comparison allows us to assess effects at the problem-solving performance level. Finally, the experimental design of the two studies enables us to compare the two control conditions (individual problem-solving with Cognitive Tutor and unsupported collaborative problem-solving). Our assumption is that neither of these conditions alone is sufficient to trigger the same quality of learning as the scripted collaboration, which combines both. Finally, a comparison across studies makes it possible to compare the differential effects of the script approaches.

Both studies are conducted in the Pittsburgh Sciences of Learning Center LearnLab facility. Classes are divided into dyads and each dyad is assigned to one of the experimental conditions. Our goal is to have 20 dyads per condition (40 students per condition, 2 studies with 3 conditions each, 120 students total). Both studies follow the general steps depicted in Table 2, with each condition varying somewhat from the general form.

Table 2: Experimental procedure in Studies 1 and 2

Pre-experimental Phase	**Individual learning with Algebra Cognitive Tutor**
	Algebra aptitude pretest
	Familiarize teacher and student with experimental setting (e.g., the collaboration scripts, the enhanced Cognitive Tutor environment)
Experimental Learning Phase	**Session 1-4: Experimental variation implemented (apply a condition from Tables 1)**
Test Phase	**Session 5: Unscripted, free collaboration**
	Session 6: Unscripted, free collaboration
	Session 7: Unscripted, free collaboration on a more challenging task (Transfer A)
	Session 8: Individual problem-solving on task comparable to those solved in sessions 1-6 (Transfer B)
	Algebra aptitude post-test and collaboration post-test (administered after session 8)

In the *pre-experimental phase*, three activities occur. First, students in all conditions use the Algebra Cognitive Tutor in normal fashion, as part of the regular algebra class curriculum. This assures relatively equal familiarity with the Cognitive Tutor across all students. Second, all students take an algebra aptitude pretest so that we can assure that student performance level is balanced across all conditions. Finally, both the teacher and the students go through a "training session" to assure familiarity with the enhanced Cognitive Tutor environment.

The *experimental learning phase* exposes the students to the particular condition being tested. For instance, the students in the collaborative script condition (either CPS or PTS) solve problems using scripts in this phase, while students in the individual problem solving condition continue to solve problems individually with the Cognitive Tutor. We have planned four sessions of the experimental learning phase to establish substantial treatment effects. Four sessions, however, is an informal choice; it may be adequate to have only two sessions or conversely, may require more than four. The key is to expose students to a particular treatment for a non-trivial amount of time, given the twin goals of domain-learning and collaborative skill learning.

In the *test phase*, students in all conditions first go through two sessions (Sessions 5 and 6) of unscripted, free collaboration on new algebra problems. Here we are interested in testing the endurance of the treatments from the learning phase, i.e., will the students in the collaborative script condition continue to follow an internalized script? Two sessions are suggested as a minimum to assess the sustaining power of script effects over time. In addition, Session 7 presents students with a more challenging problem to solve, again, in unscripted, free collaboration. This session further probes the stability of students' learning (Transfer A). In Session 8, the students work individually on problems of complexity within the range of those tackled in Sessions 1 through 6. The purpose of this session (Transfer B) is to test domain learning assessed as individual problem-solving performance. After Session 8, a post-test will be administered to all students. The post-test includes an algebra aptitude test and a test of students' knowledge about what makes good collaboration (open question format).

The dependent measures we plan to assess include: collaborative process data from collaborative problem-solving sessions (scripted and unscripted), data from individual problem-solving, performance data from an algebra aptitude test, and students' answers to a collaboration knowledge test (see Table 3).

Table 3: Overview of the dependent measures for testing script approaches

Domain Learning Hypotheses	**1. Individual problem-solving performance**
	2. Performance on algebra aptitude test
	3. Collaborative problem-solving performance when scripted
	4. Collaborative problem-solving performance in subsequent unscripted collaboration
Collaboration Learning Hypotheses	**1. Collaborative process when scripted**
	2. Collaborative process in subsequent unscripted collaboration
	3. Knowledge about what makes good collaboration (Posttest)

The *domain learning hypothesis* postulates that scripted collaboration leads to an improvement in algebra learning. As school assessment is primarily based on the evaluation of individual performance, the importance of promoting algebra aptitude and problem-solving performance at the individual level is without question. In addition, it is our assumption that it is worthwhile for students to collaborate well with one another while solving problems. This assumption is consistent with the growing importance of collaboration and teamwork in society as a whole.

The *collaboration learning hypothesis* states that scripted collaboration promotes good collaborative behaviors and learning about what makes good collaboration. Collaborative process data from scripted Sessions 1 through 4 will be analyzed to test whether our scripts trigger the kinds of collaborative interactions we expect. Analyzing collaborative process data from the subsequent unscripted sessions (Sessions 5, 6, and 7) provides information about the learning effect of the scripted collaboration. The goal of scripting is that students internalize the important elements of the script and are able to sustain good collaboration by themselves even when not scripted. If the occurrence of fruitful collaborative activities is dependent on continued scripting, the scripts will fail to achieve their purpose and our hypothesis will not be supported. The first two questions test learning of collaboration at a procedural level. It is also of interest to investigate whether students learn something about what makes good collaboration at a declarative level. To explore this question we will include open format questions about collaboration and collaborative processes on the post-test. A similar approach to assessing collaboration knowledge has proven fruitful in some of our earlier research (Rummel & Spada, 2005).

We anticipate that both of our collaboration script approaches, the PTS and the CPS, will have positive, yet varying, effects on domain learning and collaborative skill development. We anticipate that the PTS approach, in particular, will promote a form of self-reflection that will lead to improvements in domain content learning because of the demand for "reteaching" a newly acquired concept or skill. On the other hand, we expect the CPS approach to provide more meta-cognitive learning of collaborative skills by providing tasks that require and thus foster "true" collaboration between students. This is not to say that we do not expect the PTS approach to improve collaboration or the CPS approach to improve content learning. Rather, we simply anticipate stronger effects of PTS on domain learning and CPS on collaborative skill development. If our assumption is validated in this regard, it will eventually be worth investigating how we could leverage the complementary benefits of the two approaches in a single collaboration script. Such an investigation will be the subject of future work.

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